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Humus in Soil Development—Basaltic Soils in Bay of Islands, New Zealand, and New England, N.S.W.

FIONA E. ANDERSON*

Monash University

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Abstract

SOILS which have developed on basalt in certain quite comparable environments in the Bay of Islands, N.Z., and the New England Tableland, N.S.W., show pronounced morphological differences—red-yellow podzolic soils on the Kerikeri Plateau and krasnozems on the Dorrigo Plateau. Conversely, the red earths near Kawakawa, New Zealand, and the reddish-chocolate soils near Armidale, N.S.W. which show markedly similar macro- and micromorphological characteristics occur in quite dissimilar environments. The anomaly results primarily from the presence or absence of clay translocation. This process would seem to be determined by the nature of the humus form. Red-yellow podzolic soils, which show marked clay translocation in addition to the formation of clay *in situ* by weathering, develop under a mor humus form; whereas the red earths of the Bay of Islands and the reddish-chocolate and krasnozem soils of New England do not show any significant clay translocation, and are associated with a mull humus form. This soil-forming factor, though less important in studies at continental scale, may be a crucial explanatory variable in elucidating the pedogenesis of smaller areas.

INTRODUCTION

THIS paper is based on work completed in the Bay of Islands in 1962-63 and in New England, from a detailed examination of 150 soil profiles on the Tablelands between Armidale and Dorrigo. Some thin-section examination was carried out to supplement the macromorphological fieldwork. The aim of the study was to describe some of the soil processes, especially clay translocation, in both areas, and to try to account for the similarities and differences in soil morphology. Two methods were used. One involved the selection of comparable environments in order to study soil type, morphology, and process. The other required the examination of the environments of morphologically similar soil types.

It was necessary in the field research to select areas in which as many of the soil-forming factors as possible were comparable, and although climate, and hence vegetation patterns differ, differences in lithology and relief of soil sites were kept to a minimum. The geology of New England is old and complex, with sedimentary and metamorphic rocks dating back to the Silurian and Devonian; whereas in the Bay of Islands the oldest rocks are Tertiary or possibly Permian (Kear and Hay,

* Formerly Fiona E. Woods, University of New England, Armidale, N.S.W.

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1961). However, basalt occurs in both areas. In the Bay of Islands it varies in age, in the case of the Kerikeri basalts, from either Miocene (Bell and Clarke, 1909) or Pliocene? (Kear and Hay, 1961), to Holocene in the case of the Takahe basalt to the south. The New England basalts probably were all extruded in the early to mid-Tertiary (Voisey, 1945), and those near Glen Innes have recently been dated as Oligocene (Cooper *et al.,* 1963). However, in many parts of both areas lithologic similarity exists between the basalts. They are mostly dark, fine-grained olivine basalts, although many of the younger Takahe basalts in the southern area of the Bay of Islands are scoriaceous.

Basaltic Soils of the Bay of Islands

In general the soils of the Bay of Islands developing on basalt may be grouped into two subdivisions. First there are the soils which are here termed red earths, since they show remarkable similarities both in field morphology and thin section to the tropical and subtropical red earths. These would seem to correspond, at least in part, to the weakly leached Papakauri soils and the moderately leached Kiripaki soils described by Gibbs (1964). They are brownish-red to red in colour, the redder colours being associated usually with scoria and basic ash rather than with the compact basalt. The A_1 horizon is shallow and granular with a silty-clay texture. The B horizon is friable and in thin section is characterised by uniformly distributed unorientated clay and resembles the *Braunerde* fabric described by Kubiena (1948, 1953). It is suggested that this horizon is formed by the chemical processes of weathering and oxidation *in situ* with no significant additions by translocation or illuviation and as such would be described in the European nomenclature as a (B) horizon. As will be noted from Fig. 1, the depth of the horizons varies considerably from one catenary position to another. In some areas, most notably on the

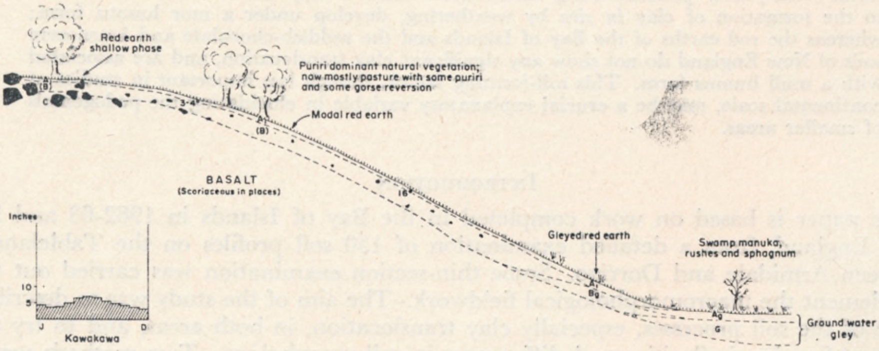

Fig. 1.—Near Kawakawa, N.Z. Generalised catenary sequence of soils on basalt, showing relationships of topography, vegetation, soil type, and climate (inset). Shallow soils with large basalt "floaters" (black) occur on the upper slopes, well developed red earths on the middle slopes, with ground-water gley soils and swamp vegetation in the valley bottom. The inset shows mean monthly rainfall at Kawakawa.

interfluves, hummocks of basaltic boulders occur and the surrounding soils are shallow and stony. On the lower slopes the profile is deep with a well-developed (B) horizon of fine subangular blocky structures and only a small percentage of small basaltic "floaters". At the base of the catena the water table is present at or near the surface for most of the year, and a gleyed red earth or ground-water gley is developing. These soils, illustrated in the generalised catenary sequence in Fig. 1, are most commonly found in the south, developing on the younger Takahe basalts, which are probably only 10,000 years old (Northland Region, 1964) and scoriaceous in places.

The second broad soil group associated with basalt in the Bay of Islands corresponds, in some respects at least, to the strongly-leached red and brown loams of Gibbs (1964). However, the division used by the writer is based primarily on the diagnostic characteristics of the B horizon. Whereas the red earths have a definite *Erde* fabric in thin section and no significant textural profile differentiation resultant upon clay illuviation, these soils are characterised by a B horizon which is heavier in texture than the A above it. When well developed the B horizon of these soils displays a *Lehm* fabric (Kubiena, 1948, 1953) in thin section, and well orientated illuviation clay skins can be clearly seen in the larger channels. In addition to clay translocation, the textural B (or B_t in the European nomenclature) horizon of these soils shows some evidence of clay forming *in situ* (by weathering) in the micropores —more or less along the lines described by Simonson (1949). These soils correspond to Simonson's description in that the A horizon is low in clay and forms only a small part of the entire profile, whereas the underlying B_t horizon is thick and the clay concentration there is much larger than can be attributed to eluviation from the A. Thus in the Bay of Islands these soils have here been termed red-yellow podzolics.

Like the red earths, the red-yellow podzolic soils vary in colour and depth from place to place, but in general they are deeper than the red earths. The A_1 of the red-yellow podzolics, although similar to that of the red earths in most respects, tends to be deeper as well as coarser in texture. Iron nodules, or concretions, are frequently

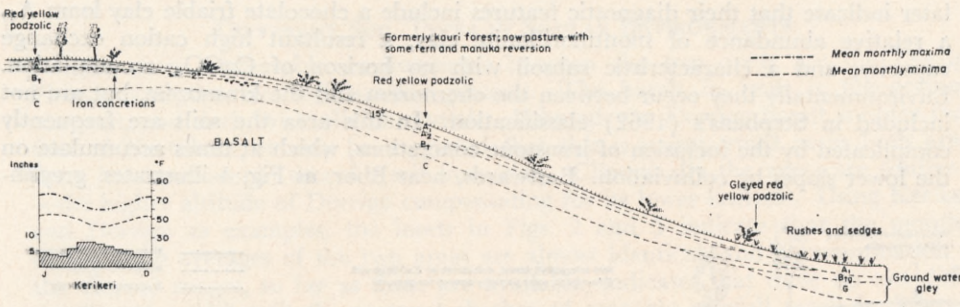

FIG. 2.—Kerikeri Plateau, N.Z. Generalised catenary sequence of soils on basalt. In a similar climatic setting to Fig. 1, but with different vegetation, red-yellow podzolic soils occur on the upper and middle slopes. (Inset: climate.)

found at the junction of the A_2 and B_t horizons (see Fig. 2), and it would appear that the older the basalt the more likely it is that ironstone concretions will be found in the soil developing upon it. These soils occur only in the wetter areas to the north and west, where the rainfall exceeds 55 inches, and are associated with the older basalt flows.

Basaltic Soils of the New England Tableland

These soils developing on basalt or basaltic alluvium/colluvium on the New England Tableland are complex and have marked catenary development. Above 4,600ft alpine humus soils are recognised (Costin *et al.*, 1952), but as the development of these tends to be associated with high altitude (not comparable with any area of the Bay of Islands) they will be ignored in this study. The remainder of the soils developing on basalt may be divided into two groups. In the west, around Armidale, the soils in general follow the catenary pattern described by Hallsworth and Gibbons (1951) for the Guyra district. However, in the area studied the lower slopes are rarely characterised by greyish-chocolate soils as described by Hallsworth and Gibbons (1951) at Guyra. Rather, this catenary position is occupied by a normal chocolate or a slightly eluviated prairie soil with the modal prairie soil in the deeper basaltic alluvium/colluvium on the lower slopes and in the valleys (see Fig. 3 for generalised catenary sequence). The chocolate soils are described by Hallsworth and Costin (1950) as "soils in which the profile shows no eluviation of sesquioxides . . . slightly acid to neutral in the surface". Hallsworth *et al.* (1952)

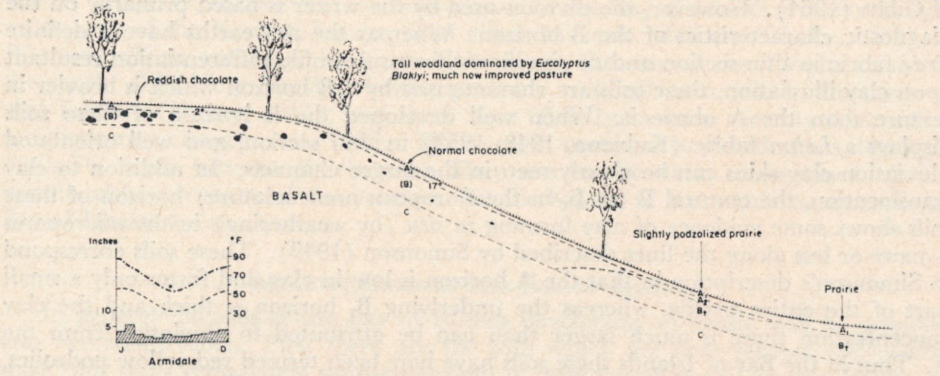

Fig. 3.—Near Armidale, N.S.W. Generalised catenary sequence of soils on basalt. As in Fig. 1, the shallow soils have numerous basalt " floaters " in the higher positions, while there are reddish-chocolate soils on the slopes. In contrast with the two New Zealand examples (Figs. 1 and 2) the rainfall at Armidale (inset) differs in seasonality and amount, and temperatures are less equable.

later indicate that their diagnostic features include a chocolate friable clay loam A_1, a relative abundance of montmorillonite clay, a resultant high cation exchange capacity, and a characteristic subsoil with no horizon of $CaCO_3$ accumulation. Environmentally they occur between the chernozem and the krasnozem, but are not included in Stephens's (1962) classification. In this area the soils are frequently complicated by the inclusion of ironstone concretions, which at times accumulate on the lower slopes by colluviation. Eastwards, near Ebor, as Fig. 4 illustrates, greyish-

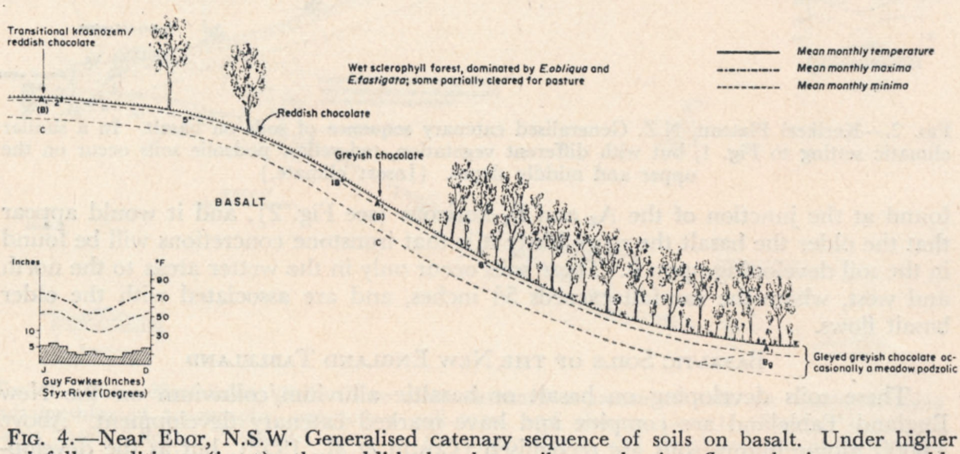

Fig. 4.—Near Ebor, N.S.W. Generalised catenary sequence of soils on basalt. Under higher rainfall conditions (inset), the reddish-chocolate soils on the interfluves begin to resemble krasnozems, and greyish-chocolate soils appear in mid-catena.

chocolate soils appear and become more widespread on the middle slopes, while the reddish-chocolate soils on the interfluves become more widespread and morphologically more krasnozem-like.

Toward Dorrigo, krasnozems occupy an increasing percentage of the catena, as illustrated in the generalised cross-section in Fig. 5. These soils are characterised by a deep, homogeneous profile with only a shallow A_1 horizon. There is no significant clay translocation, and in thin section the (B) horizon has an *Erde* fabric. Stephens (1962) indicates that the absence of profile differentiation is " because of the flocculating effect of the high content of hydrated ferric oxide, which minimises the movement of their generally kaolinitic clay by normal eluvial processes ". In

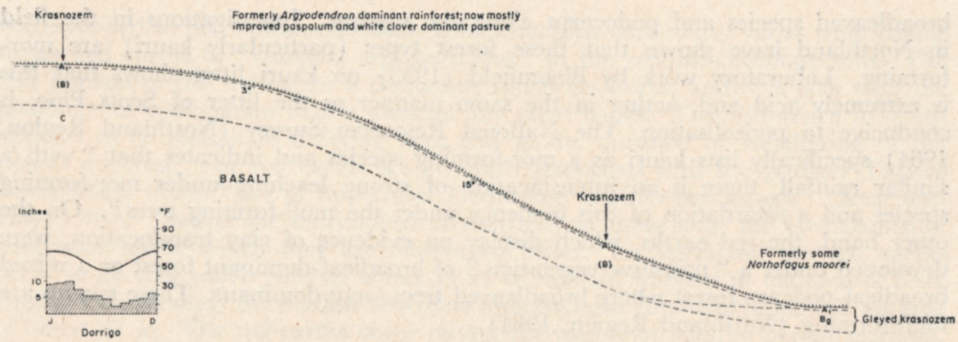

FIG. 5.—Dorrigo Plateau, N.S.W. Generalised catenary sequence of soils on basalt. Even higher rainfall at Dorrigo (inset) produces some gleying where there is interference from the ground-water table, but these soils otherwise have very little catenary differentiation.

terms of international usage these soils would seem to correspond with latosols (as noted by Stephens, 1962) or with tropical red earths, since the fabric of the (B) horizon in thin section is more of an *Erde* than a *Lehm*.

DIFFERENT SOIL TYPES IN SIMILAR ENVIRONMENTS

The most comparable environments between the two areas are the Dorrigo Plateau and the Kerikeri basaltic plateau. The basalt in both is fine-grained, compact, and dark, with olivine crystals. Although the Dorrigo basalt is older than that of Northland, it may be suggested that this is unimportant as in both areas there has been ample time for soil formation. Climatically the areas are similar——the higher altitude of Dorrigo compensating for its lower latitude. Using Kerikeri and Dorrigo as examples, the insets in Figs. 2 and 5 indicate that the monthly temperature averages of the two areas are almost identical, and an examination of the diurnal ranges, so far as these are available, indicates that these do not differ significantly. Although the seasonal rhythm of monthly rainfall totals is different (see Figs. 2 and 5) the yearly totals of 64 in. at Kerikeri and 74 in. at Dorrigo are reasonably comparable.

Yet on identical degrees of slope there are red-yellow podzolic soils on the Kerikeri Plateau and krasnozems at Dorrigo. The former show evidence of clay movement and the latter are stable homogeneous soils. It may be suggested that something in addition to the flocculating effect of the clay minerals is responsible for the differences, as this to some extent characterises the soils in both areas. It could be argued that the rainfall in the Bay of Islands is more effective than that at Dorrigo, since the maximum falls are in the winter, when the effect of evaporation is at a minimum. However, this is amply compensated for by the larger falls and greater yearly total at Dorrigo. Thus it appears that lithologic, climatic, topographic, and time differences are insufficiently divergent for clay translocation to occur in one area and not in the other, even given the importance of clay-mineral flocculation. In any explanation of this the different vegetation patterns and humus forms must therefore merit serious consideration, even though Muir (1961) indicates that there is no clear connection, on a world scale at least, between a clay-depleted A_2 and the presence or absence of raw humus.

In the Bay of Islands red-yellow podzolic soils developed under a primitive vegetation[1] of either kauri forest or a kauri-podocarp forest with a narrow fringe of

[1] From unpublished "Primitive Vegetation" map compiled by the Department of Forestry, Kaikohe, and reproduced with permission in Woods (1963). It represents the distribution of the vegetation of the area before cultural intervention, but in a climatic environment similar to that of the present.

broadleaved species and podocarps along the streams. Investigations in the field in Northland have shown that these forest types (particularly kauri) are mor-forming. Laboratory work by Bloomfield (1953) on kauri litter shows that this is extremely acid and, acting in the same manner as the litter of Scots Pine, is conducive to podzolisation. The National Resources Survey (Northland Region, 1964) specifically lists kauri as a mor-forming species and indicates that " with a similar rainfall, there is an intensification of strong leaching under mor-forming species and a retardation of this tendency under the mull-forming trees ". On the other hand, the red earths, which display no evidence of clay translocation, were developed under a " primitive vegetation " of broadleaf-dominant forest or a mixed broadleaf-podcarp forest where broadleaved trees were dominant. These species are mull-forming (Northland Region, 1964).

The natural or indigenous vegetation of the krasnozems of the Dorrigo area is thought to have been broadleaved tropical rain forest with *Argyodendron* as the dominant tree (Baur, 1957). As in the Bay of Islands the vegetation was not similar over the entire krasnozemic area, and small areas of natural grassland occurred, but it seems that the dominant species were everywhere broadleaved trees or grassland. The humus form developing under such a vegetation would be a mull. As the red-yellow podzolic soils of the Bay of Islands, which have marked textural differentiation in the profile and a *Lehm* fabric in the B horizon, developed under a mor humus form, and in a similar climatic and lithologic environment on the Dorrigo Plateau, krasnozems with no textural differentiation in the profile and an *Erde* fabric developed under a mull humus form, the writer favours the hypothesis that it is the nature of the humus form that it is mainly responsible for the development of differing soil types in these similar environments.

In the Dorrigo area the humus form of the present disclimax vegetation, paspalum and white-clover dominant pasture, is a mull. It therefore perpetuates the influence of the mull humus form of the original vegetation. In the Bay of Islands the present vegetation pattern on both the red-yellow podzolics and red earths is complex, but it is predominantly white clover, paspalum, cocksfoot, and/or ratstail pasture, which is mull-forming, and in the case of red-yellow podzolics must to some extent ameliorate the effect of the mor humus form produced under the natural vegetation. This raises the problem of whether a mor humus form is necessary only to initiate clay tranlocation, which once begun continues, or alternatively whether clay movement occurs in the Bay of Islands only under a mor humus form and whether in many of the red-yellow podzolic soils now under a pasture-grass disclimax vegetation and a mull humus form translocation is no longer operative, and in fact these are to this extent fossil soils related to the natural vegetation cover.

Similar Soil Types in Dissimilar Environments

A marked morphological similarity exists between the red earths of the Bay of Islands and the chocolate, especially the reddish-chocolate, soils of the Northern Tablelands. Both soil types have a shallow, yellow-brown to dark-brown, silty clay loam A_1 horizon with well-developed crumb structures. These are finely porous when dry. With the exception of one red-earth profile, the pH of the A horizon at all sites varied only from 5.8 to 6.0. The (B) horizon varies in colour in both but it is usually a clay-loam with small to medium subangular blocky structures and a pH varying from 5.9 to 6.6 in the red earths and from 5.7 to 6.2 in the reddish-chocolate soils. Both soil types often contain numerous basaltic " floaters ". In order to substantiate this apparent similarity, the red earths were studied in relation to the comparative table of diagnostic properties of the euchrozem, chernozem, reddish-chocolate, and krasnozem soil types in Hallsworth *et al.* (1953, p. 324). This demonstrated that in every detail except handling consistency the red earths closely corresponded to the reddish-chocolate soils. Handling consistency varies from friable in the red earths to " compact and tenacious " in the reddish-chocolate soils. The (B) horizon of the red earths is frequently much shallower, and it is only with the assistance of colluviation that it assumes any great depth. This difference in depth appears to be related to differing ages and to the duration of weathering of the parent material. The red earths are generally associated with the younger Takahe basalt flows, which " are of uppermost Pleistocene to Holocene in age " (Kear and Hay, 1961). Despite the morphological similarity of these soils, the environmental conditions under which they are developing differ. In Northland the red earths occur in an area which receives about 55 in. of rainfall, whereas in the area of New England under study the reddish-chocolate soils are most commonly found in an area of about 31 in. The red earths occur on a great variety of basaltic parent material, from young, highly vesicular scoria to compact, fine-grained massive basalt. Indeed, there is greater variety of parent material within the Bay of Islands environment than in the areas with reddish-chocolate soils in New England.

As noted previously, the red earths developed under a natural vegetation of broadleaved or broadleaf-podocarp forest in both of which taraire was the dominant species. The chocolate soils of New England are said (Hallsworth *et al.,* 1952) to be associated with a natural vegetation of tall woodland dominated by *Eucalyptus blakelyi* and *E. albens*. All these communities, as well as the present disclimax pastures of both areas, are mull-forming.

In terms of the development of these soils in such different environments, there is a problem associated with the duration of weathering. Most frequently the red earths are associated with the younger basalt flows and scoria cones, and in consequence they may be immature soils, as suggested by the N.Z. Soil Survey (Gibbs, 1964). That survey describes all the soils developing on basalt in this area as red and brown loams and subdivides them on the basis of maturity, that is, on the amount of leaching that has occurred: " the most leached (and the most mature) of the brown loams occur on the gently undulating surface of the older basalt sheets " (Northland Region, 1964). This would imply that at least some of the red earths are merely immature red-yellow podzolic soils and that, given a longer time, they could become greatly leached and develop the B_t horizon characteristic of the red-yellow podzolic rather than merely increase the depth of the (B) horizon so characteristic of the red earths and reddish-chocolate soils. However, in other areas of the Bay of Islands red earths do occur on the older basalt flows, associated with a " primitive vegetation " of mull-forming broadleaf-podocarp (taraire dominant) forest, thus emphasising the importance of the humus form in soil process and development.

In Australasia much emphasis has been given to the study of climate, parent material, relief, and time as soil-forming factors, but scant attention has been devoted to the vegetation cover and the nature of the humus form. For example, McGarity (1963), although indicating that all five of the soil-forming factors (Jenny, 1941) are essential for the development of any soil, states that " the complicated pattern of distribution of great soil groups (in northern New South Wales) . . . is largely a consequence of differences in climate, relief, parent material, and the time factor " and that " it appears that climate on a continental basis, geology on a regional basis, and topography on a local basis can satisfactorily account for the present general distribution of soils in northern New South Wales ". While not questioning the accuracy of these views in a general sense, the conclusions of the present enquiry suggest that in any attempt to provide a reasonably detailed explanation of soil-type distribution based on morphology and genesis, the vegetation—more specifically the nature of the humus form—should not be ignored.

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MRS F. E. ANDERSON,
Department of Geography.
Monash University,
Clayton, Vic., 3168,
Australia.

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